Title of Investigation:

Improved Contacts for Large Volume Cadmium Zinc Telluride Detectors

Principal Investigator:

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Other In-house Members of the Team:

Dr. Jack Tueller (Code 661), Sachidananda Babu (Code 553), and Dr. Feng Yan (Code 553)

External Collaborators:

Dr. Jonathan Grindlay (Harvard-Smithsonian Center for Astrophysics)

Initiation Year:

FY 2004

Aggregate Amount of Funding Authorized in FY 2003 and Earlier Years:

$0

FY 2004 Authorized Funding:

$50,000

Actual or Expected Expenditure of FY 2004 Funding:

In-house: $48,000;
Contracts: $2,000 (Raytheon ITSS)

Status of Investigation at End of FY 2004:

Transition to other funding: EXIST project, Neil Gehrels (Code 661); and InFOCuS project, Jack Tueller (Code 661)

Expected Completion Date:

October 2005

Purpose of Investigation:

The goal of this investigation is to develop improved conventional metal on semiconductor (CMOS) contacts for cadmium zinc telluride (CdZnTe), which is a semiconductor material used to make detectors, including ones that sense and image high-energy X-ray and gamma-ray radiation. One key challenge for the CdZnTe technology is the development of large-volume pixellated detectors, which means that the detector is segmented into pixels or individual pads. Currently, different types of Bridgman furnaces are available to grow CdZnTe crystals suitable for making detectors. The Modified Horizontal Bridgman (MHB) process recently has shown promise for producing large-volume, defect-free (single-crystal) detectors. In our investigation, we examined new CMOS contact configurations for MHB CdZnTe that would improve detector performance.

FY 2004 Accomplishments:

This program built on existing in-house CdZnTe detector fabrication capabilities that were developed for programs such as the SWIFT Burst Alert Telescope (BAT), the Constellation X High Energy X-ray Telescope (HXT) and the International Focusing Optics Collaboration for m-Crab Sensitivity (InFOCuS). Hence, processing steps, such as cleaning, etching, and passivation (a surface treatment designed to increase the surface resistance), and a shadow mask deposition technology were well established. The majority of this previous work was done using CdZnTe grown by the High-Pressure Vertical Bridgman (HPVB) process. The study was designed to investigate and to improve the contact configuration and contact deposition processes (recipes) for MHB CdZnTe.

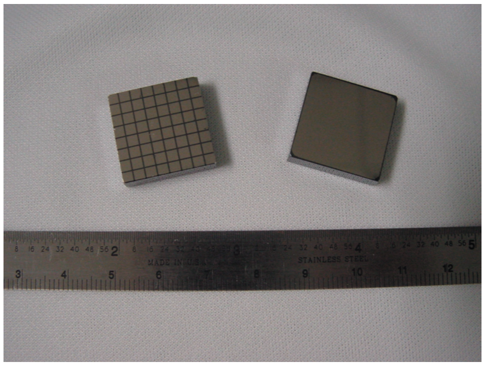

Figure 1. Optical photograph of 20 by 20 by 5 mm CdZnTe detectors. An 8 by 8 pixel anode, with 300 mm interpixel spacing, is shown on the left and a planar cathode is shown on the right.

The initial efforts with MHB CdZnTe involved producing pixellated detectors on specimens that were approximately 20 mm by 20 mm by 5 mm. The detectors had 8 by 8 pixels on a 2.46 mm pitch, with interpixel spacings of 600, 300 and 100 mm. Example detectors are shown in Figure 1. We began by fabricating detectors with a blocking cathode (planar contact) and a blocking anode (pixel contacts). A blocking cathode prevents the injection of electrons at the cathode. An ohmic cathode would allow electrons to be injected. Platinum (Pt) was selected as the contact metal, as the high work function of Pt should produce a blocking contact on the intentionally doped n-type MHB CdZnTe. In addition, Pt has historically shown good adhesion to CdZnTe.

We fabricated 14 detectors with the blocking cathode and anode configuration (Pt/Pt) with an approximately 70% yield, where yield was based on spectral resolution at 60 keV (Am^{241}). Figure 2 compares the typical spectral performance of MHB CdZnTe detectors with ohmic contacts (In/In) to the blocking contacts (Pt/Pt). Figure 3 compares the typical current-voltage (IV) curves for the two configurations. These results suggest that the blocking contacts suppress the leakage current noise and thus allow for the application of the high-bias voltages necessary for full charge collection and good energy resolution. Eight of the good Pt/Pt detectors were sent to Dr. Jonathan Grindlay at the Harvard-Smithsonian Center for Astrophysics for further testing. Harvard has the capability to test all 64 pixels on the detectors we fabricated. The test setup at Goddard only could test one pixel at a time.

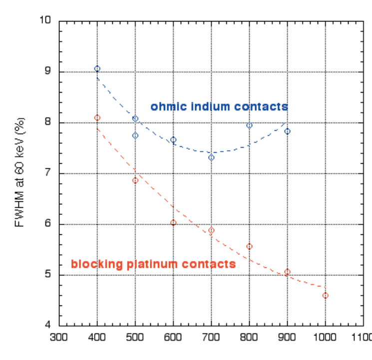

Figure 2. Plot of full width at half maximum (FWHM) at 60 keV as a function of bias voltage for ohmic versus blocking contacts. For the ohmic contacts, the FWHM begins to increase at bias voltages above 700 V due to excessive leakage current noise. For the blocking contacts, leakage current noise is suppressed allowing for higher bias voltages and the accompanying improved charge collection.

During in-house testing of the Pt/Pt detectors, we discovered that the spectral performance drifted with time. This drift involves a downward shift in the 60 keV peak channel position and degradation in the spectral resolution. Figure 3 shows Am^{241} spectra as a function of time, which clearly shows the drift. Long-duration tests (several days) on In/In detectors showed a stable spectral performance. We suspected that the drift in the Pt/Pt detectors was created by a space charge build-up near the anode due to electron accumulation created by the blocking contact. The belief was that the space charge build-up affected the electric field and hence the weighting potential for charge collection.

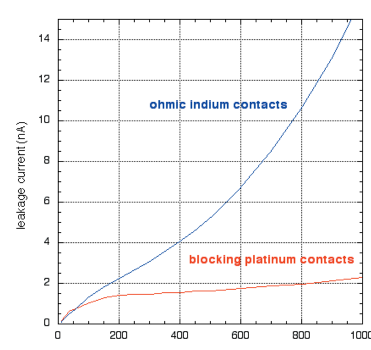

Figure 3. IV curves for ohmic versus blocking contacts. The leakage current for the ohmic contacts at high bias voltages (1000 V) is approximately an order of magnitude higher than for the blocking contacts. Note that only the positive bias portion of the curve is plotted. The IV curves are symmetric at negative bias voltages.

The proposed fix for the drift, while still taking advantage of the improved performance gained by the blocking Pt contacts, was to fabricate detectors with a blocking cathode in combination with an ohmic anode. First, we developed a new ohmic contact to replace In. The In contacts are not compatible with two of the more promising packaging schemes for CdZnTe pixellated detectors. One scheme uses low melting point solder bumps. The solder itself contains In and when heated the solder reacts with the contact and was shown to wick the In contact off the detector surface. The second scheme uses gold (Au) stud bumps and Au and In form brittle intermetallic compounds. Based on tabulated work functions, we selected titanium (Ti) as a candidate ohmic contact. First, several detectors with Ti cathodes and anodes were fabricated. The spectral performance and IV curve characteristics of the Ti/Ti detectors were almost identical to In/In detectors. In addition, the spectral performance of the Ti/Ti was stable as is the case with the In/In detectors. This development of an ohmic contact to replace In is one of the key accomplishments of the program.

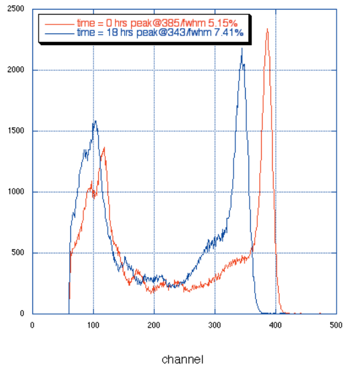

Figure 4. Am^{241} spectra collected at two different times demonstrate the drift in spectral performance seen in detectors with blocking contacts (Pt/Pt). Note the downward shift in the 60 keV peak channel position and the degradation in spectral resolution (FWHM).

Next, we produced several detectors with a blocking anode in combination with an ohmic anode (Pt/Ti). These detectors exhibited the same improved spectral performance as seen with the Pt/Pt detectors, but unfortunately, these detectors also exhibited the drift in spectral performance that was seen in the Pt/Pt detectors. This result required that we revisit our theory for explaining the drift. One possible explanation is that holes, not electrons, are responsible for the space charge build-up and the resultant drift. A thorough literature survey revealed several papers that suggest that electrons injected at the cathode recombine with slow moving holes (the hole mobility in CdZnTe is several orders of magnitude less than the electron mobility), thus compensating for the holes. It should be noted that we also found papers that did not adhere to this theory.

One attempt to better understand the mechanism for the drift involved measurement of the spectral drift as a function of the gamma-ray flux. If non-compensated holes were responsible for the drift, then we would expect the drift rate to increase with increasing gamma-ray flux. We found that the rate of the drift was independent of the flux rate for average gamma count rates between 100 and 15000 counts per second. This result is shown in Figure 5, which shows that the rate of drift is a function of time and is independent of flux rate. For example, the first and second tests were run at the same flux rate, yet the second test at this flux rate has a slower drift rate. Likewise, the last test in the sequence, which had the highest flux rate, has the slowest drift rate.

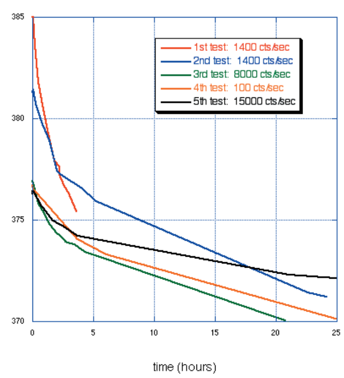

Figure 5. Plots of 60 keV peak channel position versus time at several different gamma-ray flux rates. These plots show that the drift is not a function of flux rate, which suggests that non-compensated holes are not the mechanism responsible for the performance drift.

These results suggest that deep-level electron traps in the material are playing a role in the performance drift. The traps appear to have a relatively long de-trapping time. We are currently conducting experiments to see if we can accelerate the de-trapping by grounding the anode and cathode and elevating the detector temperature. This could be practically implemented for ground-based medical imaging applications, but would be problematic for space applications.

Publications and Conference Presentations:

Performance results from pixilated detectors with Pt/Pt blocking contacts produced under this program were published and presented at the SPIE Hard X-ray and Gamma-Ray Detector Physics VI Conference in August 2004. The paper was titled, "Multipixel characterization of imaging CZT detectors for hard X-ray imaging and spectroscopy."

Planned Future Work:

Future work will focus on devising and conducting tests that identify and quantify the mechanism responsible for the spectral drift seen in Pt/PT and Pt/Ti configurations.

Summary:

The program investigated new CMOS contacting schemes for X-ray and gamma-ray detectors made from MHB CdZnTe. The new schemes were designed to reduce detector noise and improve detector performance. The MHB growth process has shown the potential to produce large volume, defect-free detectors. The new contacting schemes developed in this program have the potential to improve detector performance, making this type of CdZnTe a viable alternative for future high-energy, X-ray and gamma-ray missions, including the Energetic X-ray Imaging Survey Telescope (EXIST), which plans to fly an 8 m2 detector array. The primary criterion for success would be the production of MHB CdZnTe pixellated detectors, with spectral performance comparable to those produced by other methods. The primary risk associated with the development is the variability that we see in the CdZnTe material. As a consequence, even though our process is consistent, the detector's performance varies.